EFFECT OF FIBER LOADING ON MECHANICAL BEHAVIOR OF CHOPPED GLASS FIBER REINFORCED POLYMER COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Bachelor of Technology in Mechanical Engineering

BY

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CERTIFICATE

This is to certify that the thesis entitled "***Effect of Fiber Loading on Mechanical Behavior of Chopped Glass Fiber Reinforced Polymer Composites*"** submitted by **Bijesh K (Roll Number: 10603052)** in partial fulfillment of the requirements for the award of ***Bachelor of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

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A C K N O W L E D G E M E N T

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A B S T R A C T

Chopped strand mat glass fibre reinforced polymer composites is widely used in many industrial applications particularly in the automotive industry due to advantages such as low weight, ease of processing, price and noise suppression. Although a great deal of work has been reported in the literature which discuss the mechanical behavior of fiber reinforced polymer composites, however, very limited work has been done on effect of fiber loading on mechanical behavior of chopped glass fiber reinforced epoxy composites. Against this background, the present research work has been undertaken, with an objective to explore the potential of chopped glass fiber as a reinforcing material in polymer composites and to investigate its effect on the mechanical behavior of the resulting composites. The present research work thus aims to develop chopped glass fiber based polymer composites and study the influence of fiber loading on their mechanical behavior. Finally the morphology of fractured surfaces is examined by using scanning electron microscopy (SEM) after tensile, impact and flexural tests.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1. Overview of composite materials

The concept of composite materials is ancient: to combine different materials to produce a new material with performance unattainable by the individual constituents. An example is adding straw to mud for building stronger mud walls. Some more recent examples, but before engineered materials became prominent, are carbon black in rubber, steel rods in concrete, cement/asphalt mixed with sand, fiberglass in resin etc. In nature, examples abound: a coconut palm leaf, cellulose fibers in a lignin matrix (wood), collagen fibers in an apatite matrix (bone) etc.

A composite material consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases, with an interface separating them. It has characteristics that are not depicted by any of the components in isolation. Most commonly, composite materials have a bulk phase, which is continuous, called the matrix, and one dispersed, non-continuous, phase called the reinforcement, which is usually harder and stronger. The function of individual components has been described as:

- **Matrix phase**

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

- **Dispersed (reinforcing) phase**

The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Many of common materials(metal alloys, doped Ceramics and Polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical properties of steel are similar to those of pure iron).

There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, polymer) and the second is based on the material structure:

1.2. Classification of composites

- **Based on matrix material**

Metal Matrix Composites (MMC): Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Metal Matrix Composites have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

Ceramic Matrix Composites (CMC): Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase). One of the main objectives in producing ceramic matrix composites is to increase the toughness. Ceramic fibers, such as Alumina and SiC (silicon carbide) are advantageous in very high temperature applications, and also where environmental attack is an issue. Since ceramics have poor properties in tension and shear, most applications as reinforcement are in the particulate form (e.g. zinc and calcium phosphates) Ceramic Matrix Composites (CMC's) used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

Polymer Matrix Composites (PMC): Most commonly used matrix materials are polymeric. The reasons for this are two-fold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and does not require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reason polymer composites developed rapidly and soon became popular for structural applications. Polymer composites are used because overall properties of the composites are superior to those of the individual polymers. They have a greater elastic modulus than the neat polymer but are not as brittle as ceramics. Polymeric matrix composites are composed of a matrix from thermoset (unsaturated polyester, epoxy or thermoplastic polycarbonate, polyvinylchloride, nylon, polystyrene and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

The potential applications of polymer composites include consumer goods (sewing machines, doors, bathtubs, tables, chairs, computers, printers, etc), sporting goods industry (golf shafts, tennis rackets, snow skis, fishing rods, etc.), aerospace industry (doors, horizontal and vertical stabilizers, wing skins, fin boxes, flaps, and various other structural components), marine applications (passenger ferries, power boats, buoys, etc.), automotive industry (bumper beam, seat/load floor, hood radiator support, roof panel and land transport systems like cars, trucks and bus bodies, railway coach components, containers and two and three wheelers), construction and civil structures (bridges, columns doors, windows and partitions and for translucent roofing sheets, prefabricated modular houses and buildings etc.), industrial applications (industrial rollers and shafts, bushings, pump and roller bearings, pistons, robot arms and others).

- **Based on reinforcing material structure**

Classification of composites: three main categories:

- particle-reinforced (large-particle and dispersion-strengthened)
- fiber-reinforced (continuous (aligned) and short fibers (aligned or random)
- structural (laminates and sandwich panels)

- **Particulate Composites:** Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles. These are the cheapest and most widely used. They fall in two categories depending on the size of the particles:
    - ✓ Composites with random orientation of particles.
    - ✓ Composites with preferred orientation of particles.

Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

- **Fibrous Composites:**

Short fiber reinforced composites:

Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter). They are classified as

- ✓ Composites with random orientation of fibers.
- ✓ Composites with preferred orientation of fibers.

Long-fiber reinforced composites:

Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.

- ✓ Unidirectional orientation of fibers.
- ✓ Bidirectional orientation of fibers (woven).

❖ **Laminate Composites**

When a fiber reinforced composite consists of several layers with different fiber orientations,it is called multilayer composite.

1.3. Advantages of Composites

Advantages of composites over their conventional counterparts are the ability to meet diverse design requirements with significant weight savings as well as strength-to-weight ratio. Some advantages of composite materials over conventional ones are as follows:

- Tensile strength of composites is four to six times greater than that of steel or aluminium (depending on the reinforcements).
- Improved torsional stiffness and impact properties.
- Higher fatigue endurance limit (up to 60% of ultimate tensile strength).
- 30% - 40% lighter for example any particular aluminium structures designed to the same functional requirements.
- Lower embedded energy compared to other structural metallic materials like steel, aluminium etc.
- Composites are less noisy while in operation and provide lower vibration transmission than metals.
- Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements.
- Long life offer excellent fatigue, impact, environmental resistance and reduce maintenance.
- Composites enjoy reduced life cycle cost compared to metals.
- Composites exhibit excellent corrosion resistance and fire retardancy.
- Improved appearance with smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites.
- Composite parts can eliminate joints / fasteners, providing part simplification and integrated design compared to conventional metallic parts.

1.4. Applications of composites

Composites, it is the fastest growing "materials" market segment. Sporting goods, Aircraft, automobile, shipbuilding, are just a few examples.

Tennis rackets, golf clubs, bumpers, door panels, dashboard, even engine components of modern automobiles; look closely at a Boeing 777etc. Some applications are given below,

- Paints and coatings
- Electrical systems and electronics
- Aircraft industry, Ex: Doors and elevators
- Consumer and marine applications
- Aerospace applications
- Chemical industry, Ex: Tanks, Pipes, Pressure vessels
- Automotive body frames, engine components.

1.5. Fiber Reinforced Polymer Composites

Because of their favourable properties (e.g. high specific tensile and compressive strength, controllable electrical conductivity, low coefficient of thermal expansion, good fatigue resistance and suitability for the production of complex shape materials), fibre-reinforced composites are very widely used. According to papers, they have become the alternatives of conventional structural materials such as, steel, wood or metals in many applications. Typical areas of composite applications are car industry, aircraft fabrication, wind power plant, boats, ships, etc. During the human history, composites made occasionally large breakthroughs in construction and other materials. Nowadays, the situation has been the same with modern fibre-reinforced composites for which mass production of polymers provided stable background [1–8].

Generally, reinforced plastic composites consist of different reinforcement materials in a polymer matrix that are classified as thermoplastic and thermoset. Thermosets are polymers which undergo a curing reaction or chemical cross-linking where a resin with a relatively low molecular weight is converted into another with a high molecular weight. It is important to remark that thermosets are much more rigid than the commonly used bulk thermoplastics (e.g. HDPE, LDPE, PP, PS, etc.). The choice of thermoset matrices is considerable and the commonest groups of them are polyesters, epoxies, phenolics and polyimides [9]. Epoxys are the most widely used thermosetting resins because of its easy processing. Polyesters could not be applied for technological purposes without reinforcing because of low strength and brittleness, but they are intensively used for composite matrices [10,11]. The glass-fibre (GF) composites are the most widespread among fibre-reinforced materials due to their favourable mechanical and economical characteristics. For industrial application, the E- and S-type glass fibres are the most commonly used because they have the most favourable cost-mechanical properties relationships. Thermoset composites have been applied in the last 1940s in aircraft industry for the first time. Those materials were laminated polyester composites, and the first application was the cover of radar antennas because there was a need for such non-metallic materials that allowed radio waves through free from distortions. The manufactured parts were found to have better weight/volume ratio than the ones made from metallic materials. Since then thermoset composites have been applied as construction materials. Current civil aircraft applications have concentrated on replacing the secondary structure with fibrous composites, where the reinforcement material has either been carbon, glass, Kevlar, or hybrids of those [12].A great deal of work has been published on glass fiber reinforced polymer composites. However, very limited work has been done on effect of fiber loading on mechanical behaviour of chopped glass fiber reinforced epoxy composites. Against this background, the present research work has been undertaken, with an objective to explore the potential of chopped glass fiber as a reinforcing material in polymer composites and to investigate its effect on the mechanical behaviour of the resulting composites. The present work thus aims to develop this new class of fibre based polymer composites with different fiber loading and to analyse their mechanical behaviour by experimentation.

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Chapter 2

LITERATURE SURVEY

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This chapter outlines some of the recent reports published in literature on mechanical behaviour of glass fiber reinforced polymer composites with special emphasis on chopped glass fiber reinforced polymer composites.

Composite materials are nowadays employed in many engineering structures, such as helicopter and wind turbine rotor blades, boat hulls, and buildings, implying the application of variable loadings for long time spans. This raises the question of their fatigue behaviour, whose importance is increasingly appreciated also in the fixed-wing aircraft industry, where fatigue life has not been a major issue in the past, due to the low working strains used in practical components. Significant efforts have been devoted toward the use of lightweight structures to increase energy efficiencies in various industrial and commercial sectors [13-16].

Fiber-reinforced composites have found numerous applications in aerospace industry for their high specific strength and specific stiffness [17]. However, the cost of traditional composite materials is also considerable. Random chopped fiber-reinforced composites (RFCs) have emerged as promising alternative materials for lightweight structures due to their low cost and mass production capabilities. Their potential application in, for example, automotive industry has been documented [13, 14, 16]. In order to expand their use, accurate material characterization is required. The main difficulty in fully exploring the capabilities of the RFCs lies in the apparent impediment to effectively model their geometry at the micro-level for high fiber volume ratios (35-40%). This difficulty becomes even more obvious at high aspect ratio fibers.

Glass-fiber-reinforced composites (or glass-fiber reinforced plastics, GFRP) have seen limited use in the building and construction industry for decades [18-20]. Because of the need to repair and retrofit rapidly deteriorating infrastructure in recent years, the potential for using fiber-reinforced composites for a wider range of applications is now being realized [21-26]. These materials offer excellent resistance to environmental agents and fatigue as well as the advantages of high stiffness-to weight and strength-to-weight ratios when compared to conventional construction materials. However, one of the obstacles preventing the extensive use of composites has been a lack of long-term durability and performance data. Although there have been numerous studies of fatigue and environmental fatigue with composite materials in the past three or four decades, most of those devoted to structural composites have focused on aerospace applications. Reviews on the fatigue behavior for composite materials can be found in literature [27-30].

Mechanical properties of fibre-reinforced composites are depending on the properties of the constituent materials (type, quantity, fibre distribution and orientation, void content). Beside those properties, the nature of the interfacial bonds and the mechanisms of load transfer at the interphase also play an important role. If the building parts of composites differ in physical form and in chemical composition either, only a weak interaction can be developed at the interface. For improving the adhesion between the matrix and the fibres, there are varieties of modification technique depending on the fibre and matrices type.

The reported studies on short fiber reinforced composites by different investigators are found to have focused mostly on the strength properties of the composites. Beyerlein et al. [31] have described the influence of fiber shape in short fiber composites. Kari et al. [32] have evaluated numerically the effective material properties of composites with randomly distributed short fibers. Hine et al. [33] have presented a numerical simulation of the effects of fiber length distribution on the elastic and thermoelastic properties of short fiber composites. Fu et al. [34] have studied the flexural properties of misaligned short fiber reinforced polymers by taking into account the effects of fiber length and fiber orientation. Recently, efforts to reduce the weight of automobiles by the increased use of plastics and their composites, have led to a growing penetration of short-fibre-reinforced injection-moulded thermoplastics into fatigue-sensitive applications [35,36]. In general, short-fibre/polymer-matrix composites are much less resistant to fatigue damage than the corresponding continuous-fibre-rein- forced materials, mainly because the weak matrix has to sustain a greater proportion of the cyclic load [37].

Chopped strand mat (CSM) glass fibre-reinforced polyester (GRP) is widely used in pressure vessel and pipe line systems for the chemical industry. Glass mat thermoplastics (GMTs) are being increasingly used in the automotive industry due to advantages such as low weight, ease of processing, price and noise suppression [38]. The hot stamping of glass-mat-reinforced thermoplastics, GMT, is of great interest to the automotive industry [39-44]. Few reaserch has been done on chopped glass fiber reinforced polymer composites. Durability based design criteria for a chopped glass fiber automotive structural composite has been studied by Corum et al. [45]. Interlaminar shear fracture of chopped strand mat glass fibre reinforced polyester laminates has been studied by Zhang et al. [46]. Monotonic and tension–tension fatigue tests were carried out on E-glass chopped-strand-mat/polyester composites, varying the flexibiliser content by weight in the matrix in the range 0-30% [47]. In a previous paper [48], the static and fatigue behavior of a polyester resin with different proportions of flexibiliser was analysed. In this work, the same resin system considered was used to fabricate four chopped-strandmat/polyester (CSM) composites, which were subjected to monotonic and repeated-tension fatigue tests. The fibre volume fraction was kept low, to highlight the role played by the matrix in the mechanical response of the composite.

A study on numerical generation of a random chopped fiber composite RVE and its elastic properties has been done by Pan et. al. [49]. A study on theory of fabrication-induced anisotropy of chopped-fibre/resin panels martin has been done by Martin [50]. A study on chopped glass and recycled newspaper as reinforcement fibers in injection molded poly (lactic acid) (PLA) composites has been done [51].

Although a great deal of work has been reported in the literature which discuss the mechanical behavior of fiber reinforced polymer composites, however, very limited work has been done on effect of fiber loading on mechanical behaviour of chopped glass fiber reinforced epoxy composites. Against this background, the present research work has been undertaken, with an objective to explore the potential of chopped glass fiber as a reinforcing material in polymer composites and to investigate its effect on the mechanical behaviour of the resulting composites. The present work thus aims to develop this new class of polymer composites with different fiber loading and to analyse their mechanical behaviour by experimentation.

2.1. Objectives of the Research Work

The objectives of the project are outlined below.

- To develop a new class of chopped glass fiber based polymer composites.
- To study the effect of fiber loading on mechanical behaviour of chopped glass fiber reinforced epoxy based composites.
- Evaluation of mechanical properties such as: tensile strength, flexural strength, tensile modulus, micro-hardness, impact strength etc.

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Chapter 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the details of processing of the composites and the experimental procedures followed for their mechanical characterization. The raw materials used in this work are

1. E glass fiber (chopped strand mat)
2. Epoxy resin
3. Hardener

3.1. Specimen preparation

Chopped strand mat glass fiber (Figure 3.1) is reinforced with Epoxy LY 556 resin, chemically belonging to the 'epoxide' family is used as the matrix material. The glass fiber, epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. The fabrication of the composites is carried out through the hand lay-up technique. The low temperature curing epoxy resin (Araldite LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Composites of three different compositions such as 30wt%, 40wt% and 50wt% glass fiber are made and the designations of these composites are given in Table 3.1. The cast of each composite is cured under a load of about 50 kg for 24 hours before it removed from the mould. Then this cast is post cured in the air for another 24 hours after removing out of the mould. Specimens of suitable dimension are cut using a diamond cutter for mechanical testing. Utmost care has been taken to maintain uniformity and homogeneity of the composite.

Figure 3.1 Chopped glass fiber reinforced epoxy composite

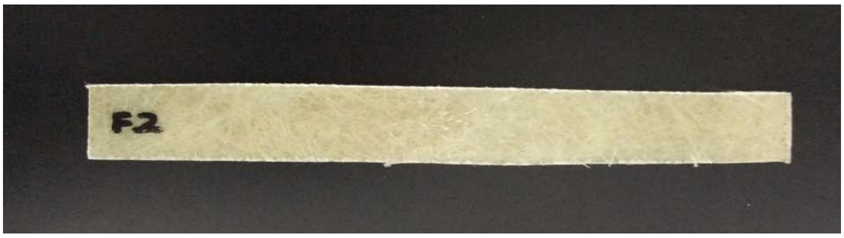
Table 3.1 Designation of Composites

Composites	Compositions
C_1	Epoxy (70wt%)+ glass fiber (30wt%)
C_2	Epoxy (60wt%)+ glass fiber (40wt%)
C_3	Epoxy (50wt%)+ glass fiber (50wt%)

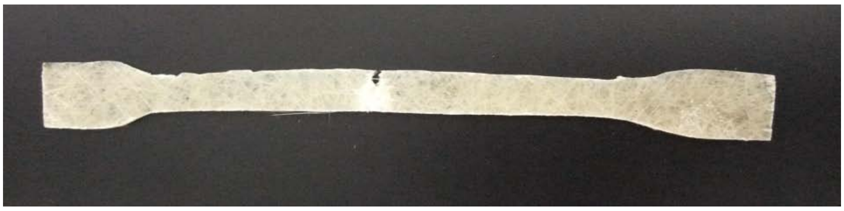
3.2. Mechanical Testing

After fabrication the test specimens were subjected to various mechanical tests as per ASTM standards. The tensile test and three-point flexural tests of composites were carried out using Instron 1195. The tensile test is generally performed on flat specimens. A uniaxial load is applied through both the ends. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F = 24.54N. Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester. The charpy impact testing machine has been used for measuring impact strength.

Figure 3. 2 shows the tested specimens for flexural, tensile, impact and hardness test respectively. Figure 3 .3 shows the experimental set up and loading arrangement for the specimens for three point bend test.

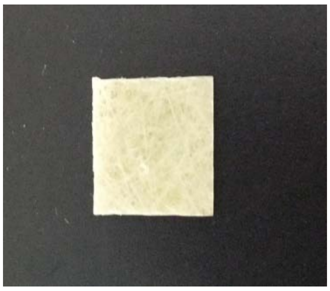


(a)



(b)

(c)



(d)

Figure 3.2 Tested specimens

Figure 3.3 Experimental set up and loading arrangement for the specimens for tensile test and three points bend test.

3.3. Scanning electron microscopy (SEM)

The scanning electron microscope (SEM) JEOL JSM-6480LV (Figure 3. 4) was used to identify the tensile fracture morphology of the composite samples. The surfaces of the composite specimens are examined directly by scanning electron microscope JEOL JSM-6480LV. The samples are washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Similarly the composite samples are mounted on stubs with silver paste. To enhance the conductivity of the samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

Figure 3.4 SEM Set up

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Chapter 4

MECHANICAL CHARACTERISTICS OF COMPOSITES: RESULTS & DISCUSSIONS

CHAPTER 4

MECHANICAL CHARACTERISTICS OF COMPOSITES: RESULTS & DISCUSSIONS

This chapter presents the mechanical properties of the chopped glass fiber reinforced epoxy composites prepared for this present investigation. Details of processing of these composites and the tests conducted on them have been described in the previous chapter. The results of various characterization tests are reported here. This includes evaluation of tensile strength, flexural strength, impact strength and micro-hardness has been studied and discussed. The interpretation of the results and the comparison among various composite samples are also presented.

4.1. Mechanical Characteristics of Composites

The characterization of the composites reveals that the fiber loading is having significant effect on the mechanical properties of composites. The properties of the composites with different fiber loading under this investigation are presented in Table 4.1.

Table 4.1 Mechanical properties of the composites

Composites	Hardness (Hv)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Impact energy (KJ/m^2)
C_1	18.4	83.20	5.81	56.12	12
C_2	19.1	137.70	5.95	107.20	14.5
C_3	24.2	122.40	6.23	160.30	15.5

4.2. Effect of fiber loading on Micro-hardness

The measured hardness values of all the three composites are presented in Figure 4.1. It can be seen that the hardness value of chopped glass fiber reinforced epoxy composites is increasing gradually with the fiber content. With the increase in fiber loading from 30wt% to 50wt% the hardness is found to have increased from about 18.4 Hv to 24.2Hv.

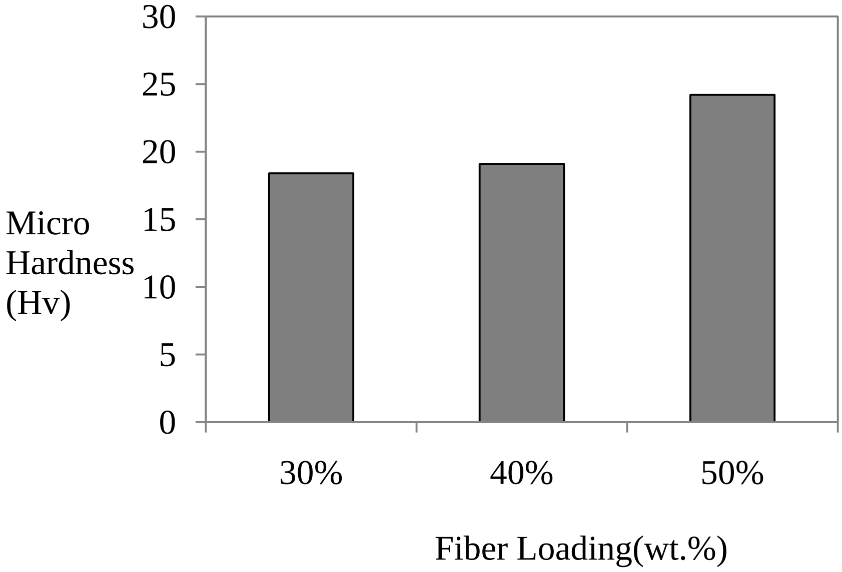


Figure 4.1 Effect of fiber loading on micro-hardness of the composites

4.3. Effect of fiber loading on Tensile Properties

The test results for tensile strengths and moduli are shown in Figures 4.2 and 4.3, respectively. It can be seen that the tensile strength of chopped glass fiber reinforced epoxy composite is more in case of composite with fiber content up to 40%. However further increase in fiber content the tensile strength value is decreasing. The increase of tensile strength may be due to the good compatibility of fiber and epoxy resin. But further increase in fiber content the strength is decreasing due to epoxy resin is not sufficient to wet the fiber. From Figure 4.3 it is clear that the fiber content has significant effect on tensile modulus of composites. Previous reports [18, 19] demonstrated that normally the fibers in the composite restrain the deformation of the matrix polymer, reducing the tensile strain. So even if the strength decreases with fiber addition, the tensile modulus of the composite is expected to increase. The same result has been observed for the chopped glass fiber reinforced epoxy composites.

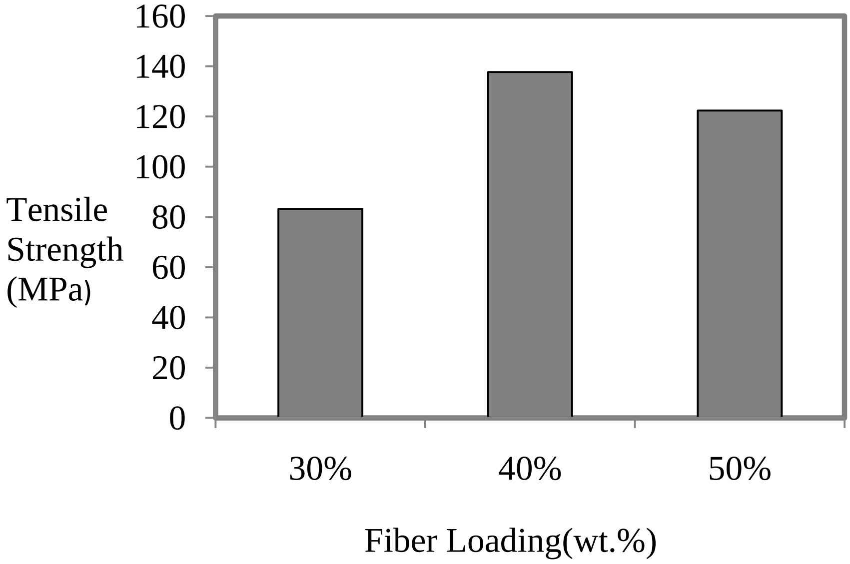


Figure 4.2 Effect of fiber loading on tensile strength of composites

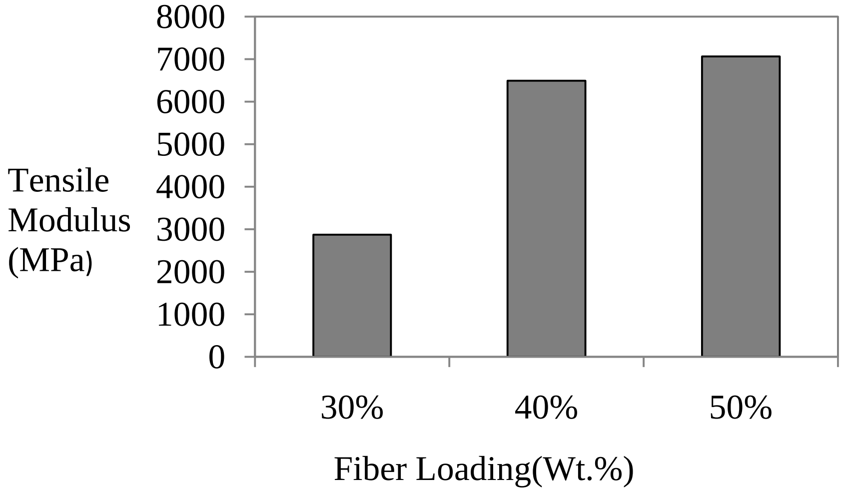


Figure 4.3 Effect of fiber loading on tensile modulus of composites

4.4. Effect of Fiber loading on Flexural Strength

Figure 4.4 shows the comparison of flexural strengths of the composites obtained experimentally from the bend tests. Composite materials used in structures are prone to fail in bending and therefore the development of new composites with improved flexural characteristics is essential. It is interesting to note that the fiber content has significant effect on tensile modulus of composites. From the figure it is clear that the flexural strength value of chopped glass fiber reinforced epoxy composites is increasing significantly with the fiber loading.

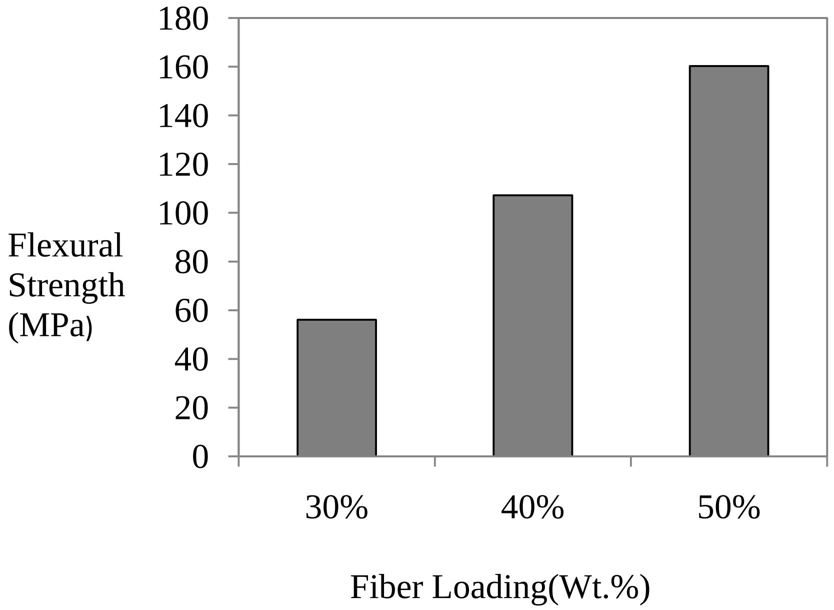


Figure 4.4 Effect of fiber loading on flexural strength of composites

4.5. Effect of fiber loading on Impact Strength

Effect of fiber loading on impact energy values of different composites is shown in Figure 4.5. High strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing properties. From the figure it is observed that resistance to impact loading of chopped glass fiber reinforced epoxy composites is increasing gradually with the increase of fiber loading.

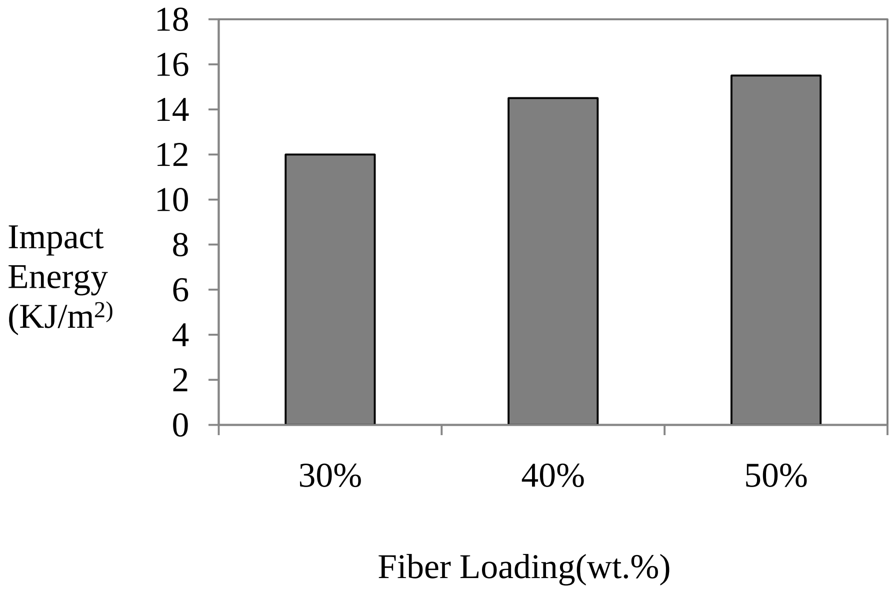


Figure 4.5 Effect of fiber loading on impact strength of composites

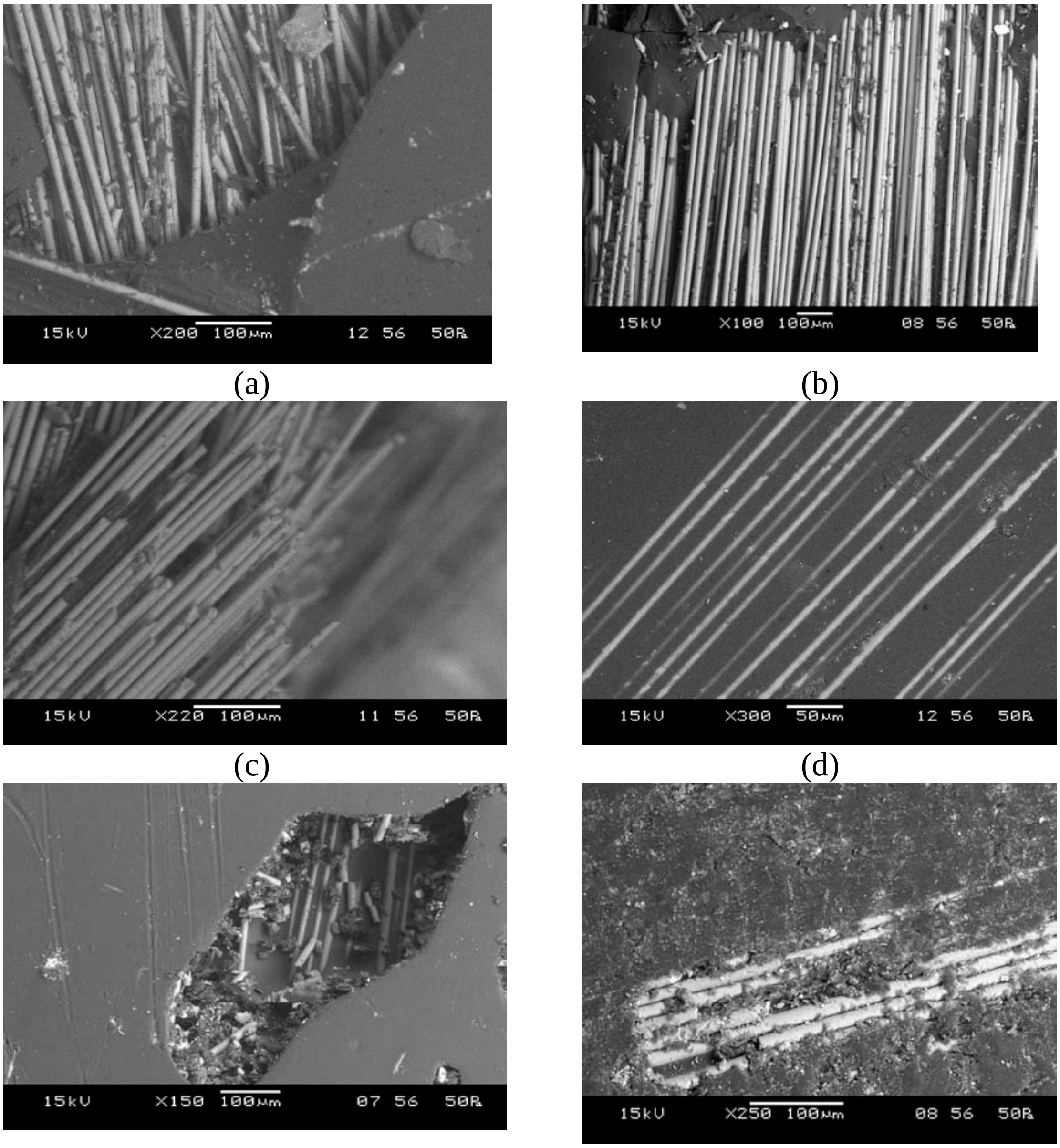
4.5. Surface morphology of the composites

The fracture surfaces study of chopped glass fiber reinforced epoxy composite after the tensile test, flexural test and impact test has been shown in Figures. From the above analysis Figure 4.2, we can conclude that the Tensile strength chopped glass fiber reinforced composites depends on the interfacial properties between fiber and matrix. During the Failure process of chopped glass fiber / matrix interface, adhesion bonding prevails prior to debonding whereas frictional stress provides resistance to slip and pullout after debonding. Therefore, both the bond stress and frictional stress between fibers and matrix have effects on the chopped glass fiber pull -out force and pull-out energy (Figure 4.6a). However, the interfacial adhesion stress can be improved by the increase of fiber loading from 30wt% to 40wt% as shown in Figure 4.6b. But on further increase of fiber loading from 40wt% to 50wt% the tensile strength decrease drastically as shown in Figure 4.2, which will be decreased because of the decreasing contact surface between fiber and matrix. Thus, it appears that the decrease of the tensile stress for some composites can be explained by the decrease of the interfacial bond stress.

Figures. 4.6c shows the fracture surface SEM micrographs of flexural strength test specimens with 30wt.% of the chopped glass fiber loading. As seen in the

Figure 4.6c, fibres normal to the loading direction were observed to fail due to expansions of other fiber as in chopped glass fibers are arranged randomly. Also, matrix cracking and fiber-fiber interface cracks are visible for the specimens. Figure 4.6d shows the fracture surface of the composite specimens with 50wt.% fiber loading. As seen in the Figure 4.6d, fibres along the loading directions were observed to buckle and fractured fibres formed fiber kinks locally. Also, longitudinal splitting, along the interlaminar region is visible. It was also observed between tensile and flexural test, the strength property of the chopped glass fiber composites may not shows promising results whereas, flexural strength results increases with increase in fiber loading. This may be due to the lower inter laminar strength of the composites made with chopped glass fiber reinforced composites.

Examination of impacted specimens (Figure 4.6e) reveals a very similar damage pattern to that seen in tensile samples (Figures 4.6a,b), in particular, mainly matrix damage at energies of up to 15.5kJ/m^2 (for 50wt% fiber loading), accompanied by fiber breakage at 12kJ/m^2 (or more) for 30wt% fiber loading (Figure 4.6e). Ignoring boundary conditions and misalignment of fibers, the fiber structure of can be considered similar when impacted in the out-of-plane direction. Thus the damage caused by low velocity impact in these three composites would be expected to be very similar for the same impact energies. Although the impact damage is very similar for the two different fiber geometries, the effect of this damage on subsequent tensile tests is significantly different, due to the highly anisotropic nature of these fiber reinforced This is consistent with the observation of matrix damage (cracking, debonding and delamination) at low energies (up to about 12kJ/m^2), accompanied by fiber breakage at impact energies of 15.5kJ/m^2 or greater as shown in Fig. 4.6f. The matrix damage caused by lower energy impact would be expected in case of 30wt% fiber loading to affect the matrix dominated material, since the matrix also plays major load bearing supports to the composites. However, such matrix damage would not be expected to have a significant effect on the fiber dominated carrying most of the load remain undamaged. This would explain the observed critical impact energy of 12kJ/m^2, below which no significant reduction in residual properties is evident. The higher the impact energy, the more fiber breakage occurred, and lower the residual tensile strength of the composites.



(a) (b)

(c) (d)

(e) (f)

Figure 4.6 Scanning electron micrographs of chopped glass fiber reinforced epoxy specimens after tensile, flexural and impact testing.

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Chapter 5

CONCLUSIONS

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CONCLUSIONS

This experimental investigation of mechanical behaviour of chopped glass fiber reinforced epoxy composites leads to the following conclusions:

- The successful fabrication of a chopped glass fiber reinforced epoxy composites with different fiber loading has been done by simple hand lay-up technique.
- It has been noticed that the mechanical properties of the composites such as micro-hardness, tensile strength, flexural strength, impact strength etc. of the composites are also greatly influenced by the fiber loading.
- The fracture surfaces study of chopped glass fiber reinforced epoxy composites after the tensile test, flexural test and impact test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.

5.1. Scope for Future Work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like effect of fiber type, fiber orientation, loading pattern, fiber treatment on mechanical behavior of chopped glass fiber reinforced polymer composites and the resulting experimental findings can be similarly analyzed.

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